Top Properties comments/highlights

Connected to readying
"Review of Top Quark Properties Measurements at the Tevatron" by Marc-André Pleier - pages 98-137
http://arxiv.org/abs/0810.5226

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Introduction to top quark properties

Top Quark:

Particle type: weak isospin partner of the bottom quark

Spin: +1/2

Mass: 172.4±1.2 GeV/c^2

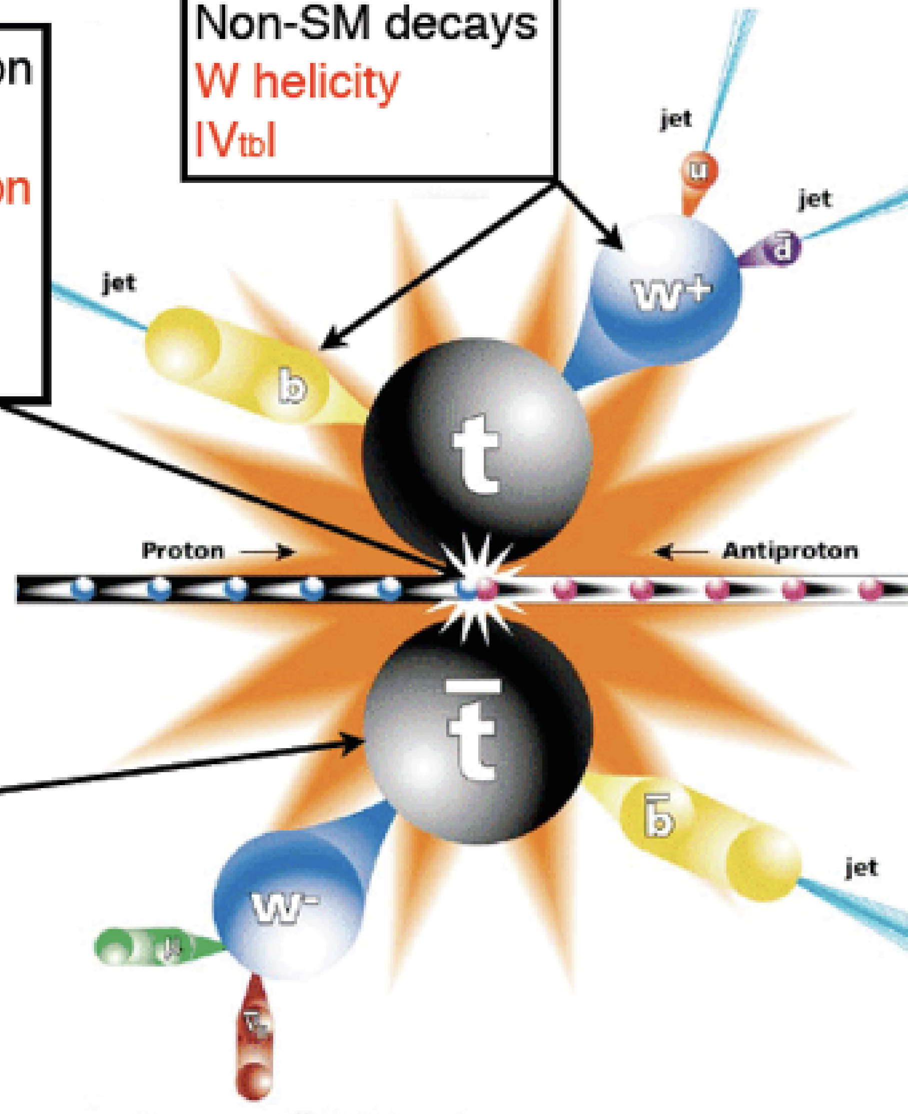
Width: ~1.5 GeV/c^2 or ~10^{-24} s

Couplings: Strong (color triplet), EM (Q=+2e/3), Weak ($I_{3,L}$=+1/2)

Decay: almost exclusively to W+b

Production cross section
FB Asymmetry
Differential cross section
Production mechanism
Resonance production
Stop, t' production

Branching ratios
Rare decays
Non-SM decays
W helicity
$|V_{tb}|$



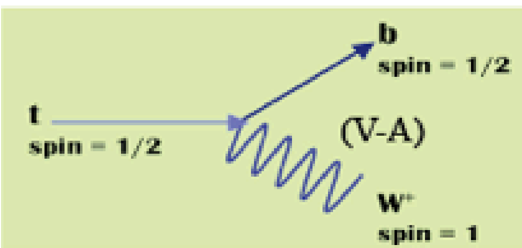
Top charge
Top spin
Top mass
Top width

Also....
Single top cross section ($|V_{tb}|$)
Anomalous coupling

Moriond 09

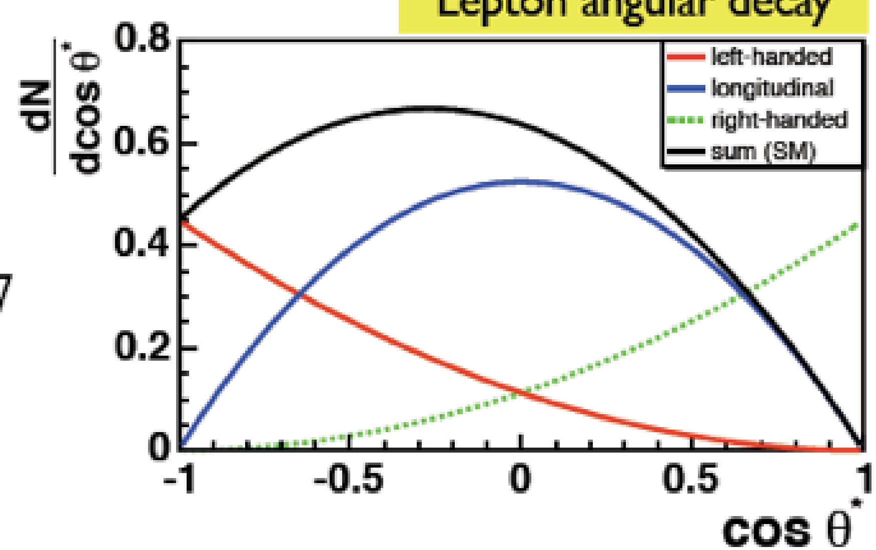
Helicity of W bosons in top decays

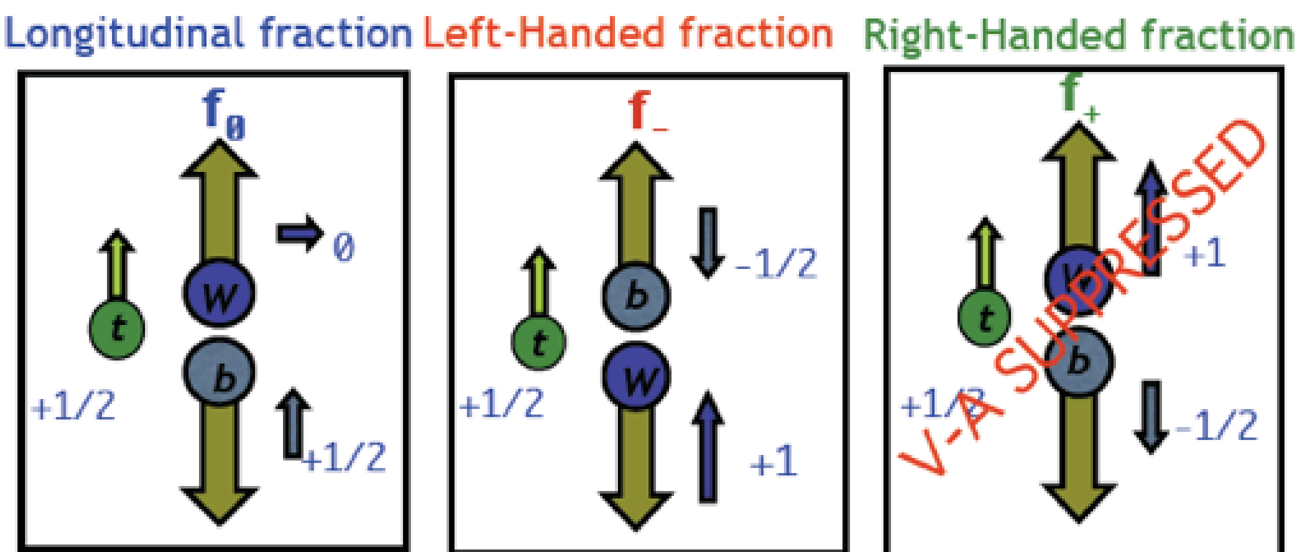
- Positive W helicity f_+ suppressed by chiral factors ~ M_b^2 / M_W^2
- Relative fraction of f_0 to f_- is:



$$f_0 = \frac{M_t^2 / 2M_W^2}{1 + M_t^2 / 2M_W^2} \cong 0.7$$

Lepton angular decay





cos θ* is the angle between the d-type fermion in the W rest frame and the W flight-direction in the top rest frame

MySummary

	f0	f-	f+
t	0.7	0.3	sup
tbar	0.7	sup	0.3

Moriond 09

IF

- it were V+A, f+=0.3
- V+A small component is there, f+ is enhanced : expect V+A<few percent at least

4 Top weak interaction

http://arxiv.org/abs/hep-ph/0008189

The standard model dictates that the top quark has the same vector-minus-axial-vector ($V-A$) charged-current weak interaction as all the other fermions, as shown in Fig. 4. It is easy to see that this implies that the W boson in top decay cannot be right handed, *i.e.*, have positive helicity.[n] The argument is sketched in Fig. 5. In the idealized limit of a massless b quark, the $V-A$ current dictates that the b quark in top decay is always left-handed.[o] If the W boson were right-handed, then the component of total angular momentum along the decay axis would be $+3/2$ (there is no component of orbital angular momentum along this axis). But the initial top quark has spin angular momentum $\pm 1/2$ along this axis, so this decay is forbidden by conservation of angular momentum. CDF has measured

$m_b/M_W \to 0$

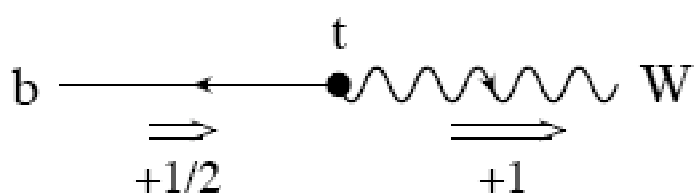


Figure 5: Illustration that the top quark cannot decay to a right-handed (positive-helicity) W boson.

The top quark may decay to a left-handed (negative helicity) or a longitudinal (zero helicity) W boson. Its coupling to a longitudinal W boson is similar to its Yukawa coupling, Eq. (4), which is enhanced with respect to the weak coupling. Therefore the top quark prefers to decay to a longitudinal W boson, with a branching ratio

$$y_t = \sqrt{2}\frac{m_t}{v} \approx 1$$

at tree level

$$BR(t \to W_0 b) = \frac{m_t^2}{m_t^2 + 2M_W^2} \approx 70\% \ .$$

The decay of the top quark into $b+W$ is governed by the following amplitude

$$\mathcal{M}(t \to bW) = \frac{ig}{\sqrt{2}} \bar{b} \; \not{\epsilon}^W \frac{1-\gamma_5}{2} t \tag{1.53}$$

Adopting the high energy limit ($m_t^2 > M_W^2$) for the polarisation vector ϵ_L of the longitudinal W (corresponding to helicity $h^W = 0$)

http://arxiv.org/abs/hep-ph/9707321

$$\varepsilon_L^W = \begin{pmatrix} p_3^W \\ 0 \\ 0 \\ p_0^W \end{pmatrix} \frac{1}{M_W} = \begin{pmatrix} p_0^W \\ 0 \\ 0 \\ p_3^W \end{pmatrix} \frac{1}{M_W} + \mathcal{O}(M_W/m_t) \tag{1.54}$$

the amplitude is dominated by contribution from longitudinal W's

$$\begin{aligned} \mathcal{M}_L &= \frac{ig}{\sqrt{2}} \bar{b} \; \not{\epsilon}_L^W \frac{1-\gamma_5}{2} t \approx \frac{ig}{\sqrt{2}} \frac{m_t}{M_W} \bar{b} \frac{1+\gamma_5}{2} t \\ &= i\sqrt{2} \frac{m_t}{v} \bar{b}(1+\gamma_5) t \end{aligned} \tag{1.55}$$

This part is thus proportional to the Yukawa coupling

$$g_Y = \sqrt{2} \frac{m_t}{v} \tag{1.56}$$

with a rate growing proportional m_t^3. In contrast, the amplitude for the decay into transverse W's, is obtained with the polarisation vectors

$$\varepsilon_T^{\pm} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ 1 \\ \pm i \\ 0 \end{pmatrix} \tag{1.57}$$

and remains constant in the high mass limit. The rate is governed by the gauge coupling g and increases only linearly with m_t. The longitudinal or transversal W is produced in http://arxiv.org/abs/hep-ph/9707321

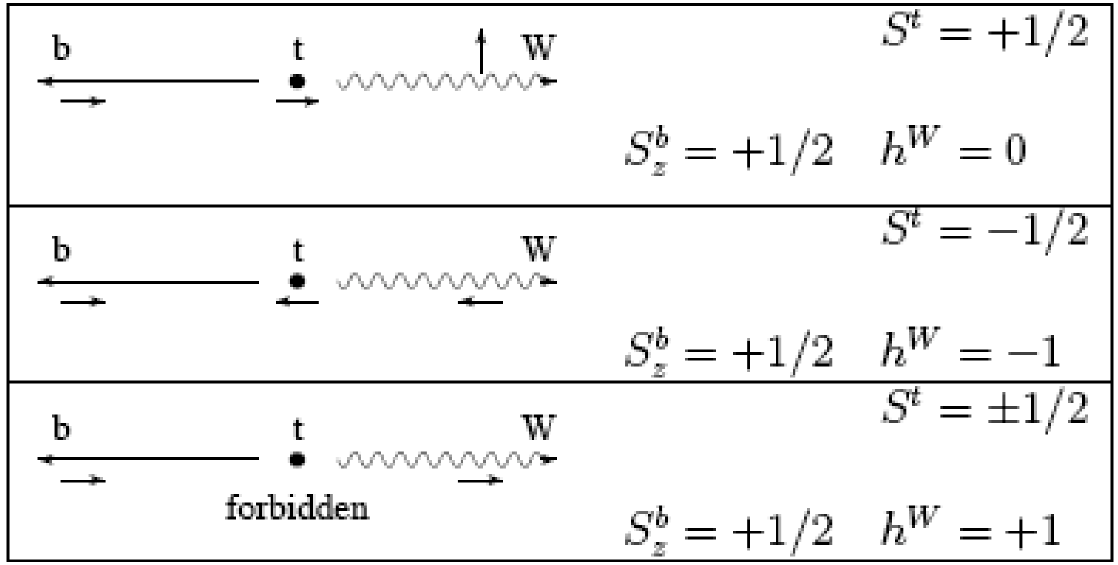


Figure 1.6: Top decays: angular momentum conservation

conjunction with a lefthanded b quark. The production of W's with helicity $h^W = +1$ is thus forbidden by angular momentum conservation (see fig. 1.6).

In total one finds

$$(h^W = -1) : (h^W = 0) : (h^W = +1) = 1 : \frac{m_t^2}{2M_W^2} : 0. \tag{1.58}$$

LONG/LH=$M_t^2/2M_W^2$

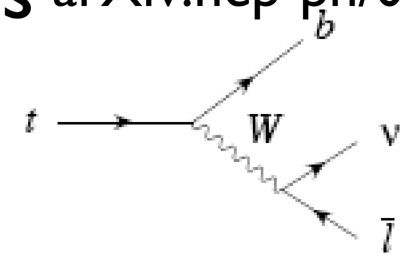
$$BR(t \to W_0 b) = \frac{m_t^2}{m_t^2 + 2M_W^2} \approx 70\% \ .$$

Formulas for ME with Spin and Helicities arXiv:hep-ph/0008189

The partial width for this decay, summed over the two spin states of the top quark, is given by a very simple formula:

$$d\Gamma \sim \sum_{\text{spin}} |\mathcal{M}|^2 \sim t \cdot \ell b \cdot \nu \,, \qquad (50)$$

where the four-momentum of the fermion or antifermion is denoted by its label.



EXAMPLE of Calculation

$$\mathcal{M}(t \to bW) = \frac{ig}{\sqrt{2}} \bar{b} \not{\epsilon}^W \frac{1-\gamma_5}{2} t$$

arXiv:hep-ph/9707321

To undo the sum over the top-quark spin, it is useful to decompose the four-momentum of the top quark, t, into two lightlike four vectors,

$$t_1^2 = t_2^2 = 0.$$

$$t = t_1 + t_2$$

$$t_1 = \frac{1}{2}(t + ms)$$

where s is the spin four-vector.

$$t_1 = \frac{1}{2}(t - ms)$$

In the top-quark rest frame, $s = (0, \hat{s})$,

In the top-quark rest frame, the spatial components of t_1 point in the spin-up direction, while the spatial components of t_2 point in the spin-down direction. The partial widths for the decay of these two spin states are

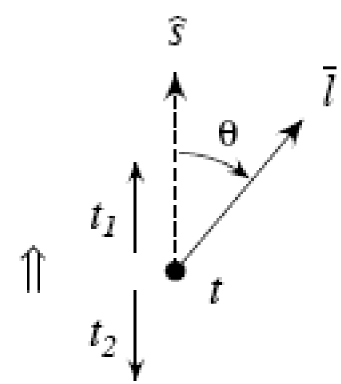
t1=(m, ms/2) t2=(m,-ms/2)

if El~pl

$$d\Gamma_\uparrow \sim t_2 \cdot \ell b \cdot \nu$$
$$d\Gamma_\downarrow \sim t_1 \cdot \ell b \cdot \nu \,.$$

t_2*l=(mE_l-(-ms*p_l))=

=mEl(1+costheta)



So if top has spin up along s

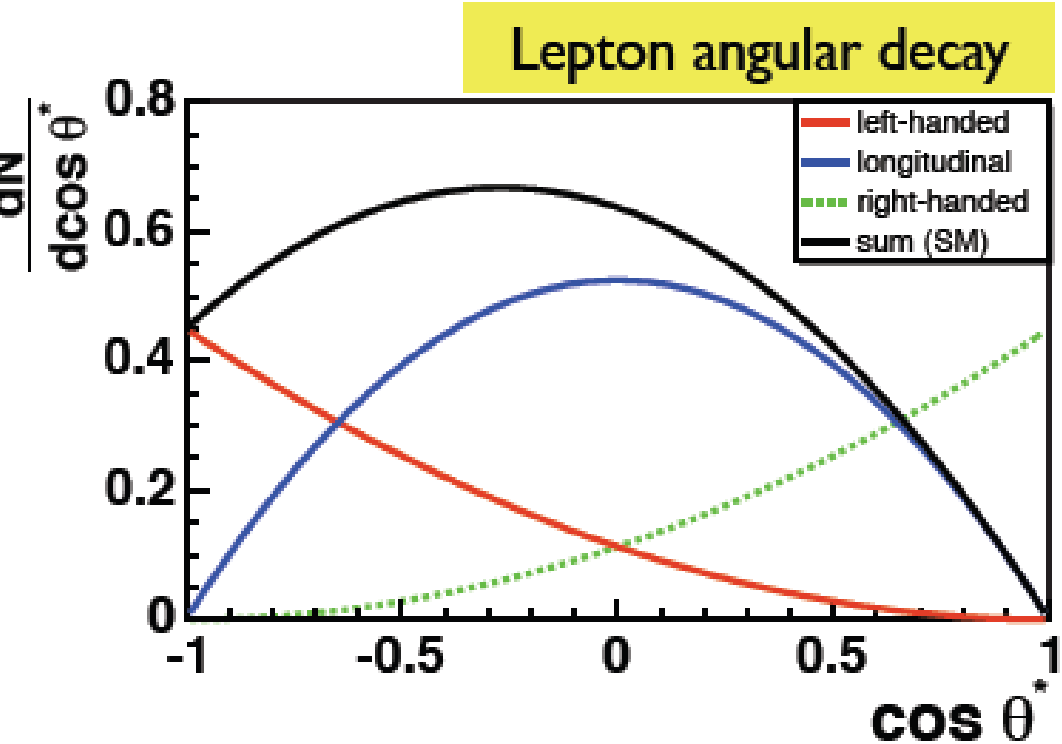
$$d\Gamma_\uparrow \sim t_2 \cdot \ell \sim 1 + \cos\theta \,,$$

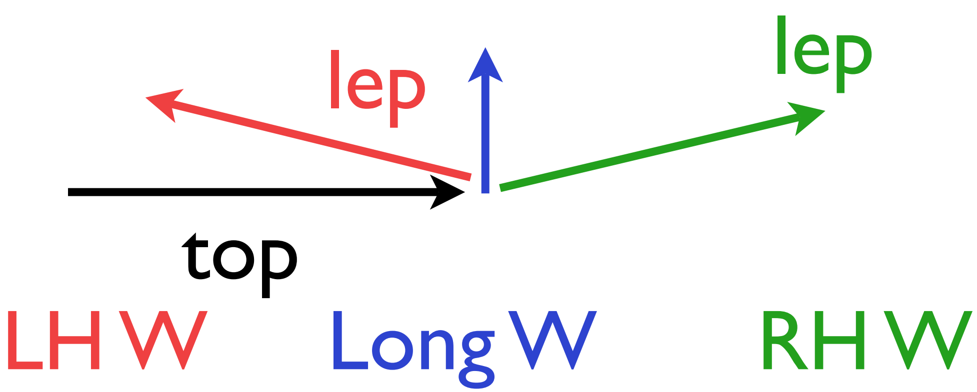
where θ is the angle between the spin direction and the charged-lepton three-momentum (see Fig. 25).

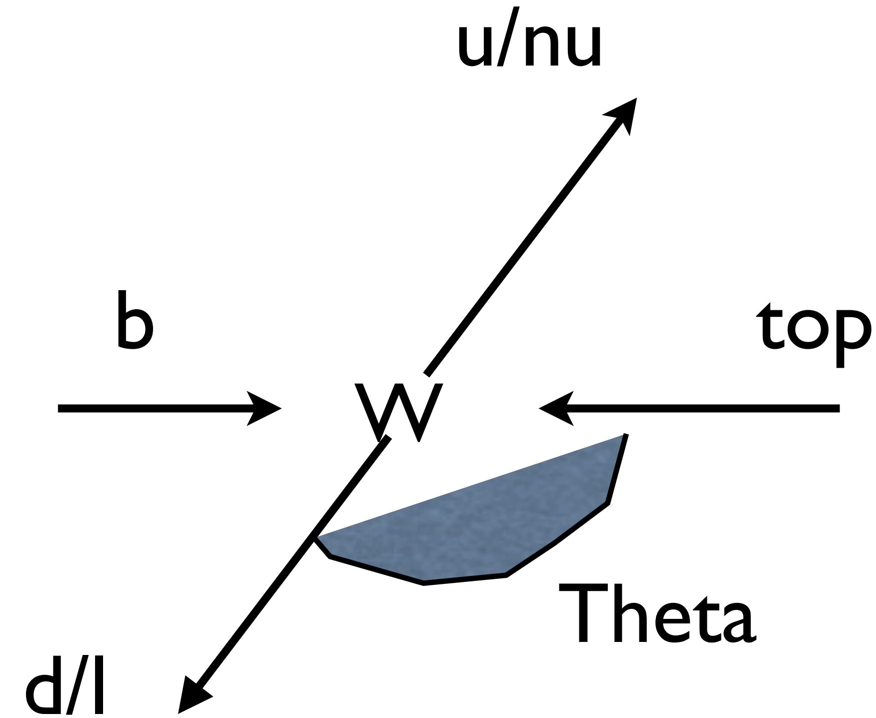
$$\frac{d\Gamma_\uparrow}{d\cos\theta} \sim 1 + \cos\theta \,,$$

Helicity

ALL IN THE W rest frame



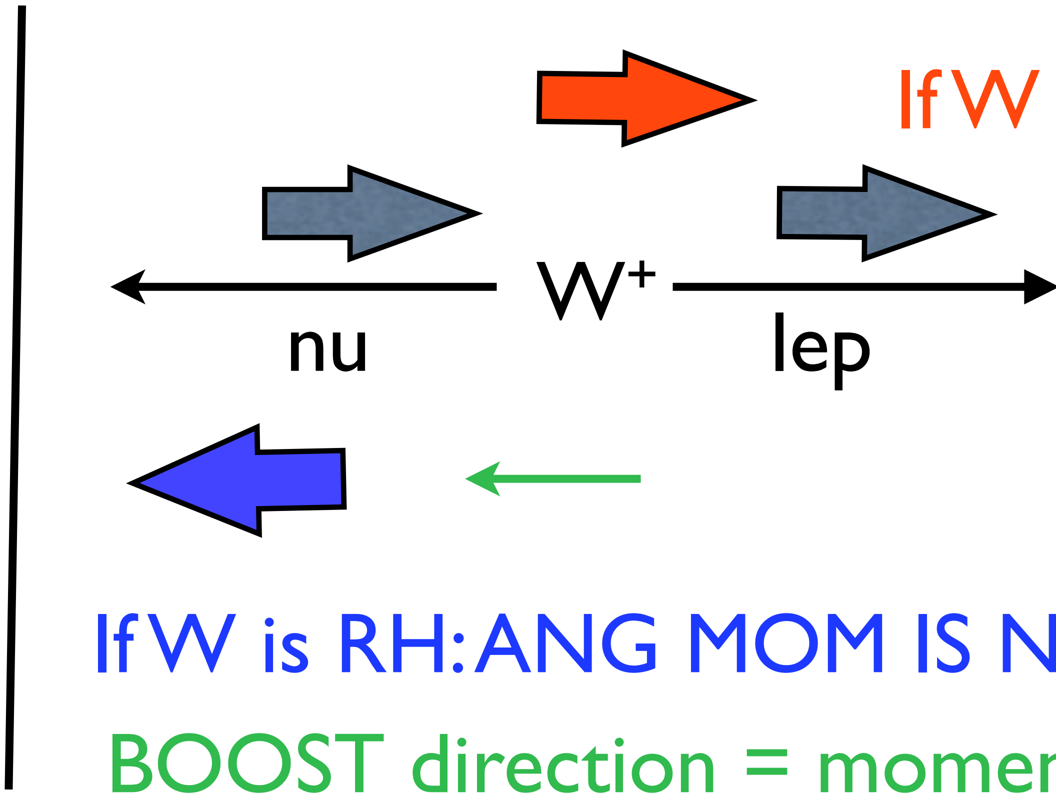




Charged lepton spectrum

nu from W+ is LH　　　lep from W+ is RH

Have Lep anti parallel to boost



If W is LH:OK

If W is RH: ANG MOM IS NOT CONSERVED

BOOST direction = momentum of W

- LH W implies anti parallel lepton: softer spectrum
- RH W implies parallel lepton: harder spectrum
- Long W: in between

M_{lb}

- To derive start from the definition, expand and use $M_{lepton} \sim 0$ + $p_{lepton} = -p_{neutrino}$

Matrix element

arXiv:hep-ex/0406031

PDF for Mt

$$P(x, M_t) = \frac{1}{\sigma(M_t)} \int \mathrm{d}\sigma(y, M_t)\mathrm{d}q_1 \mathrm{d}q_2 f(q_1) f(q_2) W(y, x)$$

$d\sigma(y, M_t)$ is the partonic theoretical differential cross section,

$W(y,x)$ is the normalized probability for the measured set of variables x to arise from a set of nascent (partonic) variables y,

$f(q)$ parton distribution functions that reflect the probability of finding any specific interacting momentum q within the proton (antiproton),

$\sigma(M_t)$ is the total cross section for producing $t\bar{t}$.

$$P_{t\bar{t}} = \frac{1}{12\sigma_{t\bar{t}}} \int d^5\Omega \sum_{\mathrm{perm.},\nu} |\mathcal{M}_{t\bar{t}}|^2 \frac{f(q_1) f(q_2)}{|q_1||q_2|} \Phi_6 W_{\mathrm{jets}}(E_{\mathrm{part}}, E_{\mathrm{jet}}),$$

$\mathcal{M}_{t\bar{t}}$ is the leading-order matrix element for $t\bar{t}$ production

the sum is over all 12 permutations of the jets and all possible neutrino solutions.

$W_{\mathrm{jets}}(E_{\mathrm{part}}, E_{\mathrm{jet}})$ corresponds to a function that maps parton-level energies E_{part} to energies measured in the detector E_{jet}, and is based on MC studies.

$$\ln L(M_t) = \sum_{i=1}^{N} \ln[c_1 P_{t\bar{t}}(x_i, M_t) + c_2 P_{\mathrm{bkg}}(x_i)] - N \int A(x) \left[c_1 P_{t\bar{t}}(x, M_t) + c_2 P_{\mathrm{bkg}}(x)\right] \mathrm{d}x,$$

ME (cont)

- LKL(M_{top})=Sum_i LKL_i(M_{top} ,event_i prop)
- minimize -LKL as a function of M_{top}

What to measure

- Helicity angle
  - Direct, need reconstruction of top and W momenta. limited by ET resolution
- Charged lepton spectrum
  - need to have separation
- Mass of lepton and b -jet system (M_{lb})
  - uses only lab four momenta, no need for top reco, need b-tag
- Matrix element
  - use all kine info

P_T^{lepton} and M_{lb}

CDF with 0.2 fb-1

- P_T^{lepton} : use l+jets and di-lep
- M_{lb} :use only l+jets kine-fit
- Fit f0 (f+) while fixing f+(f0) to cos(theta)* templates with sig+bkg

CDF with 0.7 fb-1

- kine-fit
- Fit f0 (f+) while fixing f+(f0) to costheta* templates with sig+bkg

Stat dominated, main sys=JES,bkg (shape and norm), MS stat

ME method

no simultaneous measurement

- Both D0 and CDF: l+jets + btag (D0 adds unatgged). D0 uses 0.1 fb-1, CDF 19, fb-1
- F+ is fixed to SM, get f0 from LKL fit
- D0 is dominated by mtop
- CDF by MC stat

perform LKL fit

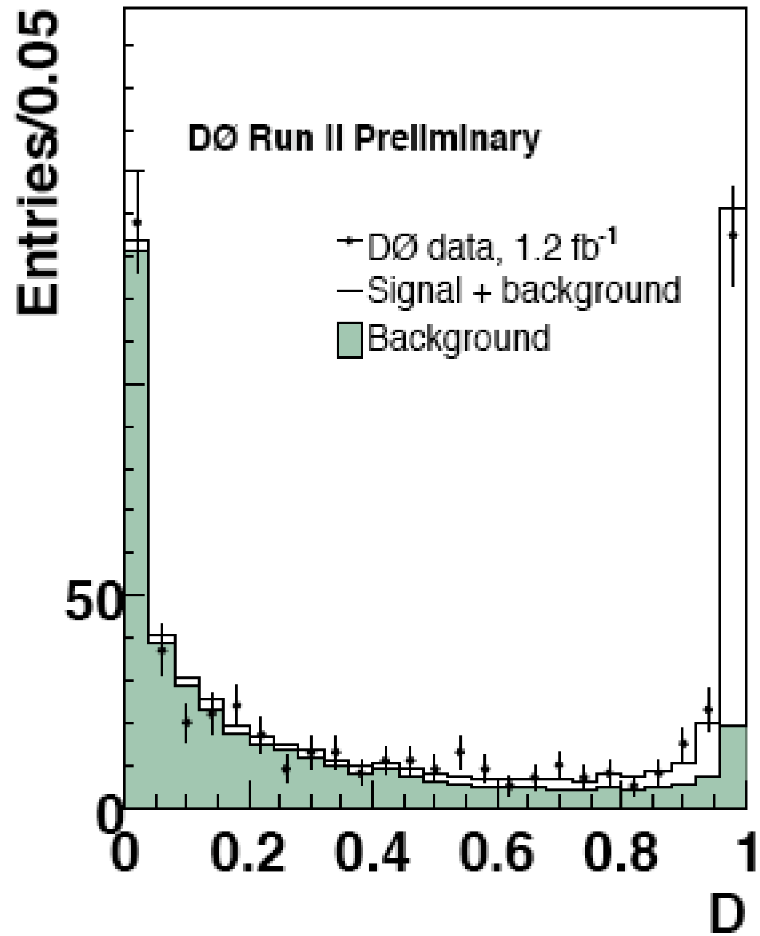


FIG. 1: Distribution of $\mathcal{D}$ for Run IIb data (points with error bars), background (shaded histogram), and signal plus background (open histogram) in the e+jets channel.

http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/TOP/T69/T69.pdf

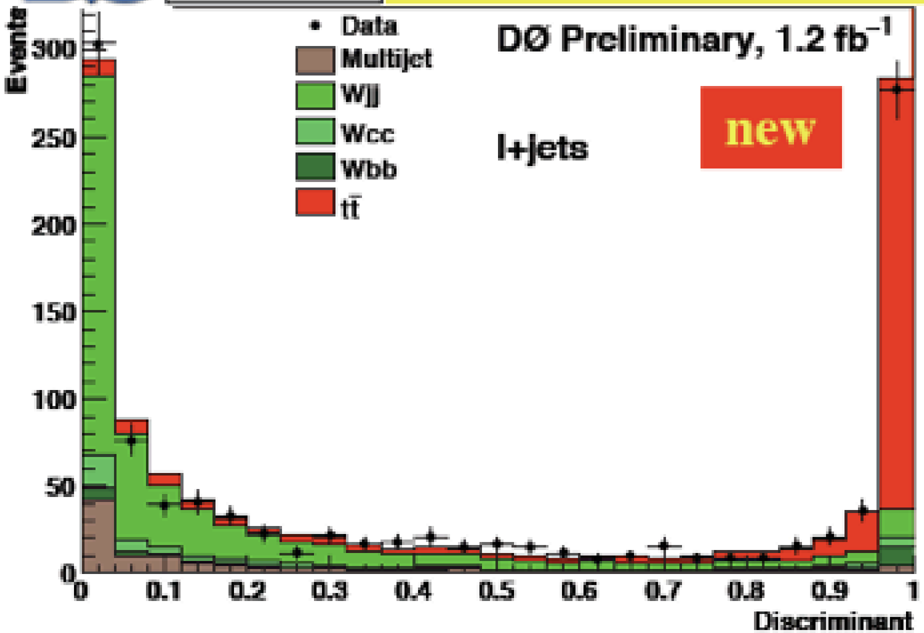
We have also studied splitting the data into various subsamples. We find good consistency between the Run IIa and Run IIb subsets (p-value of 49%), but marginal consistency between the e+jets and μ+jets samples (12%) and between the dilepton and lepton plus jets subsamples (1.6%).

Simultaneous f_0 and f_+ fractions

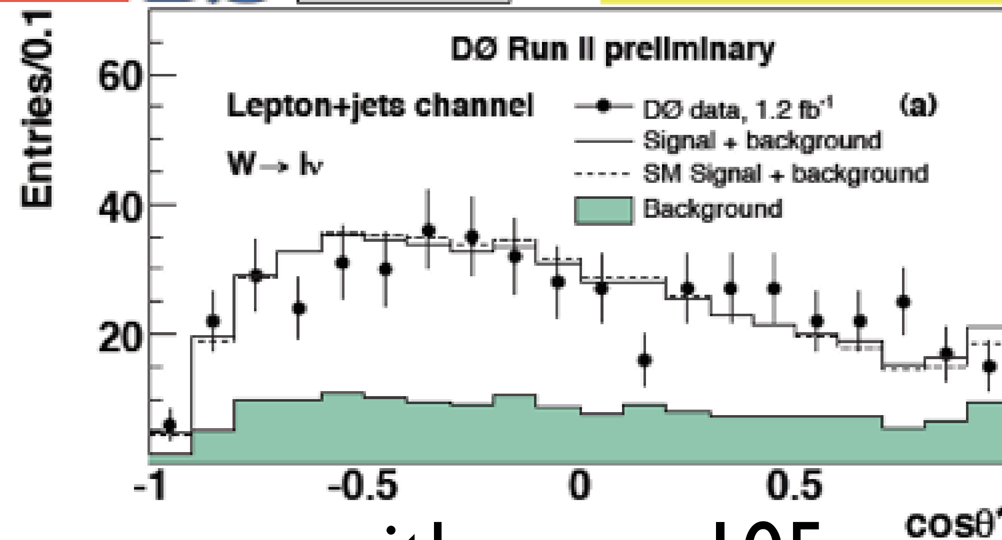
discussed in par 6.3

1.2 fb^{-1} L+jets: sample selection

new

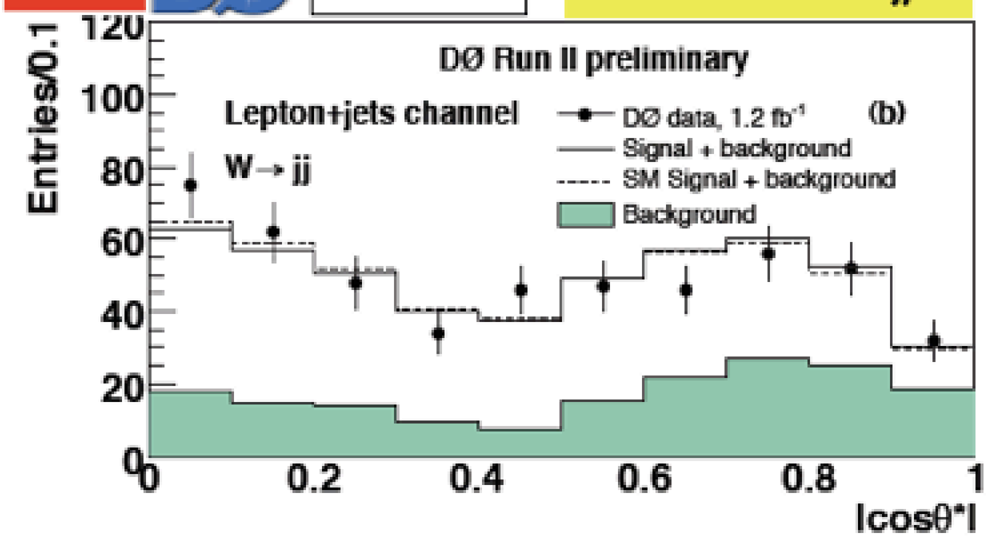


new 1.2 fb^{-1} cosθ* in W→lν

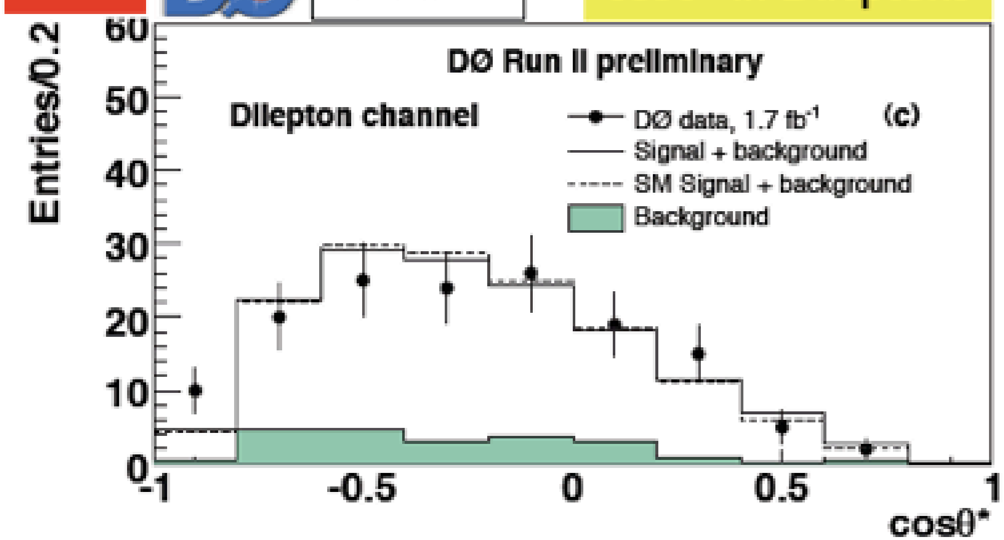


compare with page 105

new 1.2 fb^{-1} cosθ* in W→jj



new 1.7 fb^{-1} cosθ* in Dileptons



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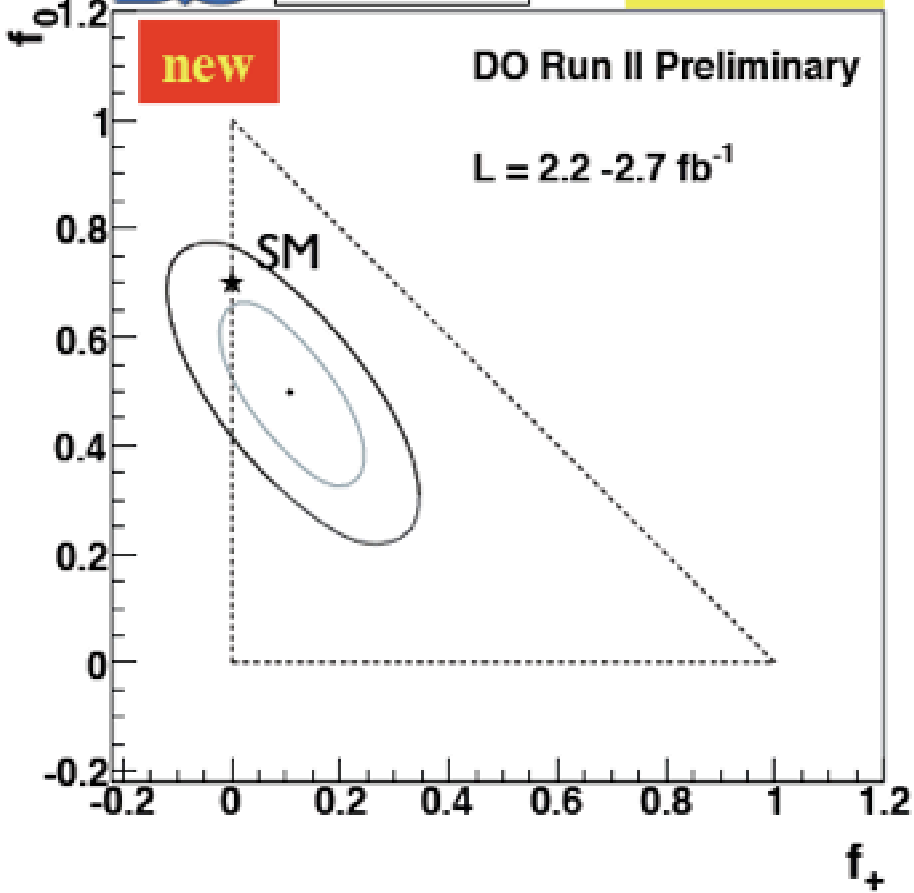
f_0 and f_+ fractions: status

reported at page 106

2.2-2.7 fb^{-1} | f_0 vs f_+



$$f_0 = 0.490 \pm 0.106\ (\text{stat.}) \pm 0.085\ (\text{syst.})$$
$$f_+ = 0.110 \pm 0.059\ (\text{stat.}) \pm 0.052\ (\text{syst.}).$$

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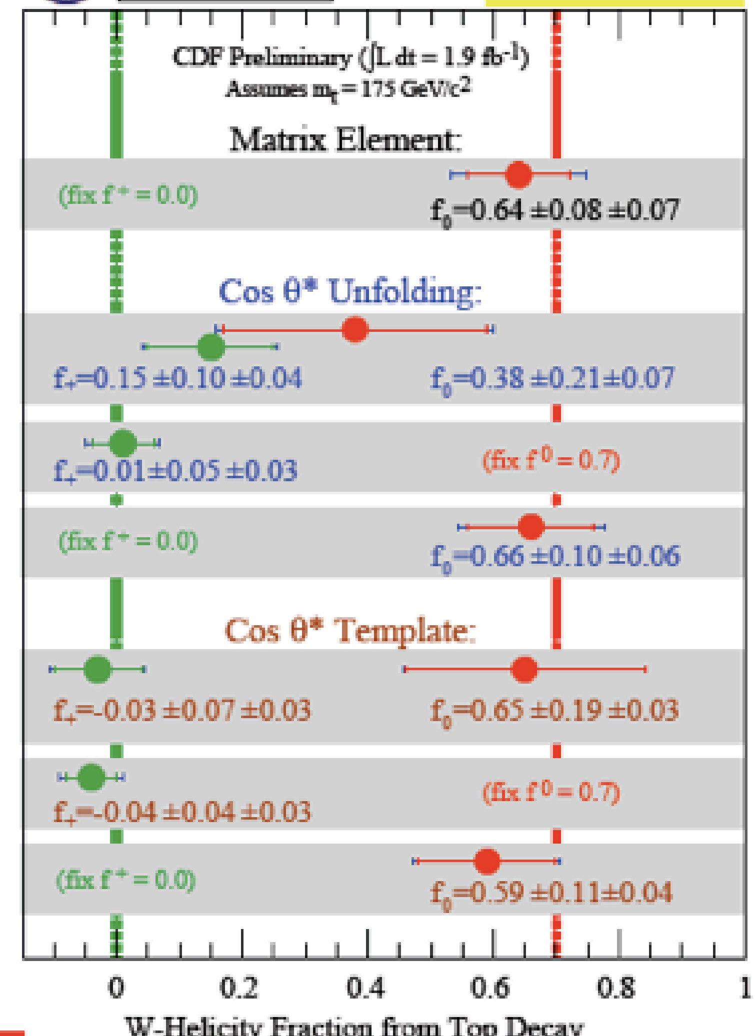
1.9 fb^{-1} | f_0 and f_+



new CDF combination of cosθ* metho

~±15% $f_0 = 0.62 \pm 0.11$ assuming $f_+ = 0.0$

$f_+ = -0.04 \pm 0.05$ assuming $f_0 = 0.7$

$f_0 = 0.66 \pm 0.16$ and $f_+ = -0.03 \pm 0.07$

$B(t \rightarrow Wb)/B(t \rightarrow Wq)$

- D0 in l+jets
- Standard sel, b-tag
- Combined fit for R and xsec

Ni is obtained by a set of equatio
taking efficiencies into account

The unknown ratio of branching fractions, R, is measured by comparing the observed number of tags in the data with expectations based on selection criteria acceptances, tagging efficiencies and background estimates.

http://arxiv.org/pdf/hep-ex/0012029

$$\mathcal{L} = \mathcal{L}_{\ell+jets}\mathcal{L}_{\text{dilepton}} \qquad \mathcal{L}_{\alpha} = \prod_i P(N_i;\bar{N}_i)\prod_j G(x_j;\bar{x}_j,\sigma_j)$$

$P(N_i;\bar{N}_i)$ is the Poisson probability for observing N_i events in each bin (the index i runs from 1 to 4 for the $l+jets$ sample and from 1 to 3 for the dilepton one) with an expected mean $\bar{N}_i$ (see Table I).

The functions $G(x_j;\bar{x}_j,\sigma_j)$ are Gaussians in x_j,

with mean $\bar{x}_j$ and variance σ_j^2, and incorporate the uncertainties in the tagging efficiencies,

If we really want to know...

of events, N_i, in each of the bins of the $l + jets$ sample can be expressed as a function of the acceptances, tagging efficiencies and the estimated background, by the following set of equations:

http://arxiv.org/pdf/hep-ex/0012029

$$N_{00} = n_0 + (1-\varepsilon_l)(1-\varepsilon_s)n_1 + (1-\varepsilon_l)^2(1-\varepsilon_s)^2 n_2 + F_{00} \quad (1a)$$

$$N_{01} = \varepsilon_l(1-\varepsilon_s)n_1 + \varepsilon_l(2-\varepsilon_l)(1-\varepsilon_s)^2 n_2 + F_{01} \quad (1b)$$

$$N_1 = \varepsilon_s n_1 + 2\varepsilon_s(1-\varepsilon_s)n_2 + F_1 \quad (1c)$$

$$N_2 = \varepsilon_s^2 n_2 + F_2 \quad (1d)$$

Here it is

with n_i $(i = 0, 1, 2)$, the number of events with i b-jets in the SVX acceptance, given by:

$$n_0 = N_{top}[a_0 + (1-R)a_1 + (1-R)^2 a_2] \quad (2a)$$

$$n_1 = N_{top}[Ra_1 + 2R(1-R)a_2] \quad (2b)$$

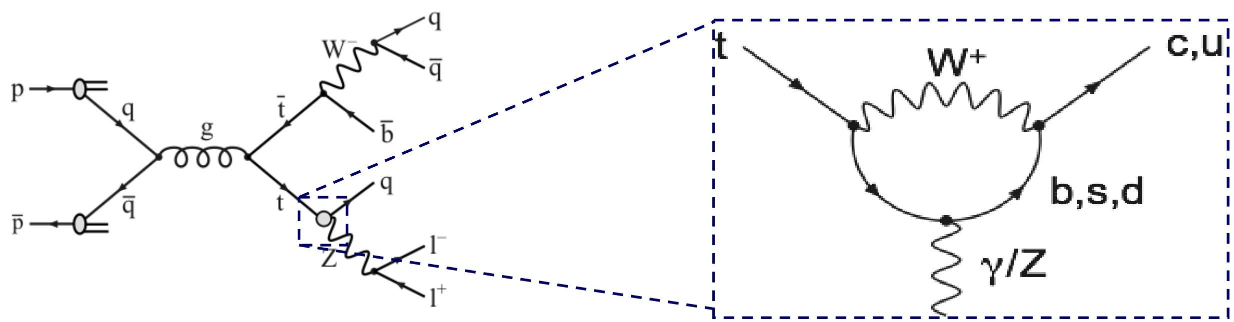
$$n_2 = N_{top}R^2 a_2 \quad (2c)$$

where N_{top} is the total number of $t\bar{t}$ events in the sample, F_i is the background in the i-th bin and a_i is the fraction of events containing i b-jets $(i = 0, 1, 2)$ in the acceptance. This definition of acceptance, which reflects the way the a_i's are related to R in Eq. (2a)–(2c), has been chosen in order to be able to use the standard CDF top Monte Carlo (see below) which assumes $R = 1$. For the dilepton sample, Eq. (1a) and (1b) are merged into one because SLT tagging is not used.

FCNC

Flavor Changing Neutral Currents

- No Flavor Changing Neutral Currents (FCNC) at tree level in SM.

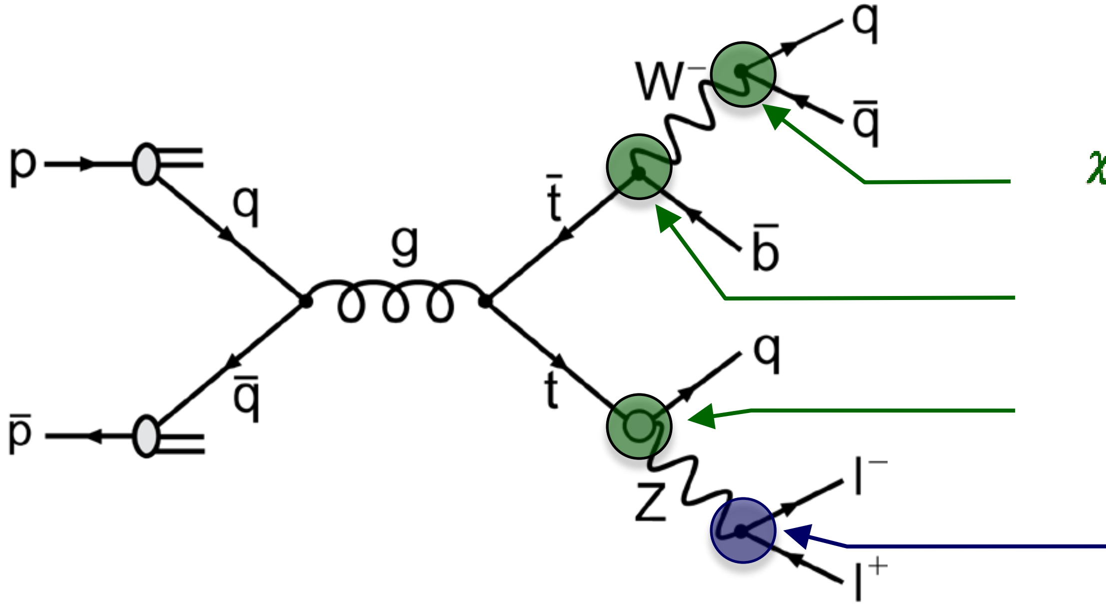


Allowed at higher orders, but heavily suppressed (GIM, small CKM element

Beyond SM models predict branching ratios up to $O(10^{-4})$…

- **SUSY, extra quark singlets , extra Higgs doublets (see hep-ph 0409342)**

- Search in the Z+4 jets channel. Event reconstruction



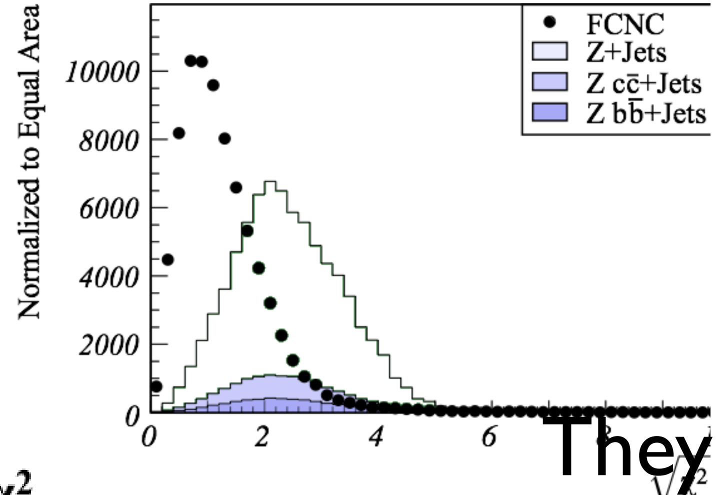
$$\chi^2_{\text{mass reco}} = \left(\frac{m_{W\ \text{recon}} - m_W}{\sigma_W}\right)^2 + \left(\frac{m_{tWb\ \text{recon}} - m_t}{\sigma_{tWb}}\right)^2 + \left(\frac{m_{tZc\ \text{recon}} - m_t}{\sigma_{tZc}}\right)^2$$

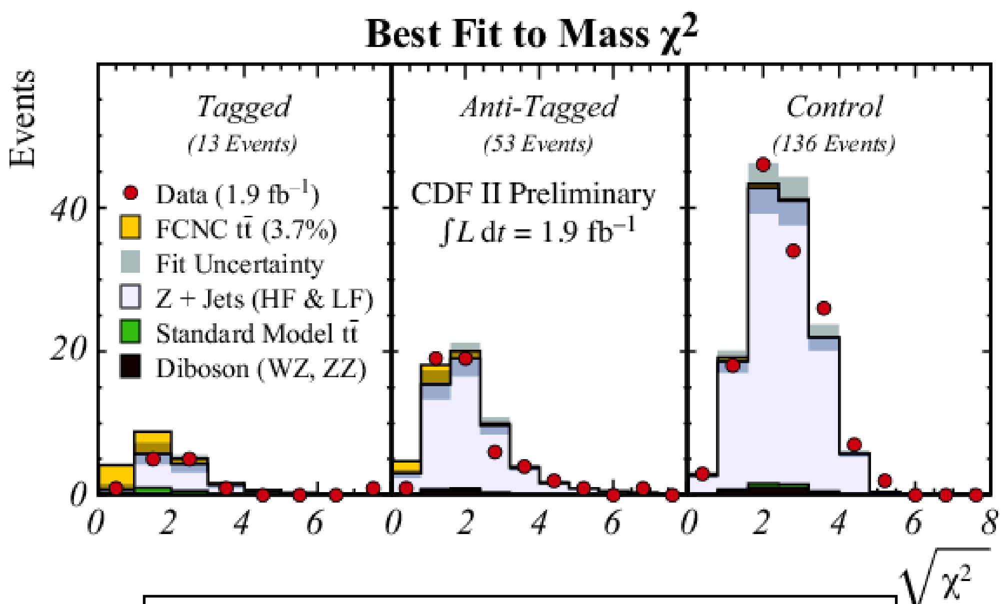
Already part of selection cuts

FCNC

Top FCNC Search: Results

- **Full reconstruction χ^2:**
  - Good discriminant power
- **Results: Signal and control regions**
  - Signal: passing kinematic cuts
    - Separate tagged from anti-tagged
  - Control: failing kinematic cuts





They discriminate with mass chisq

B(t→Zq) < 3.7% @ 95% C.L.

World's best limit. Improved previous limit (13.7% @ L3) by a factor of 3.5

FCNC

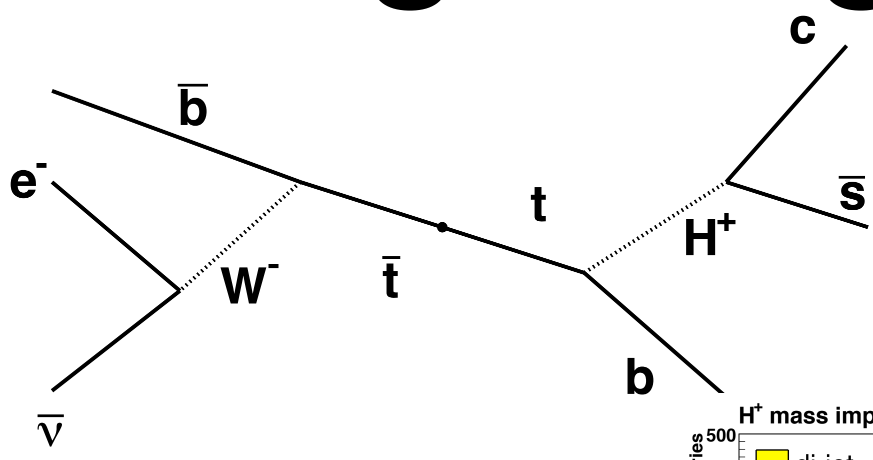
Use PYTHA to simulate FCNC

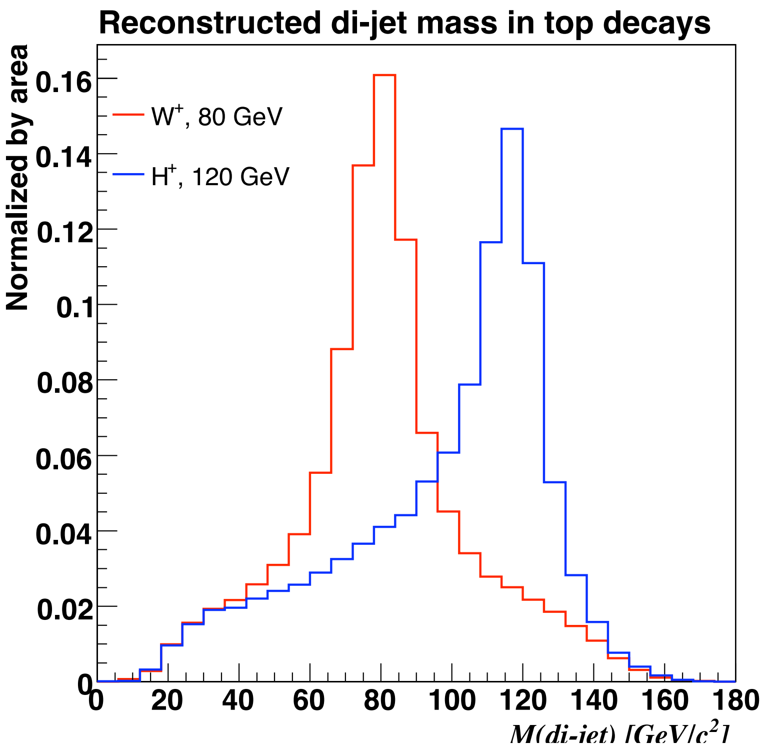
To determine the FCNC branching fraction, we take into account single or double FCNC decays of $t\bar{t}$ pairs and normalize to the event yield of a selection for the SM decay $t\bar{t} \to WbWb \to \ell\nu b\, q\bar{q}'b$ ("lepton+jets") requiring at least two jets to be secondary vertex b-tagged [16]. In

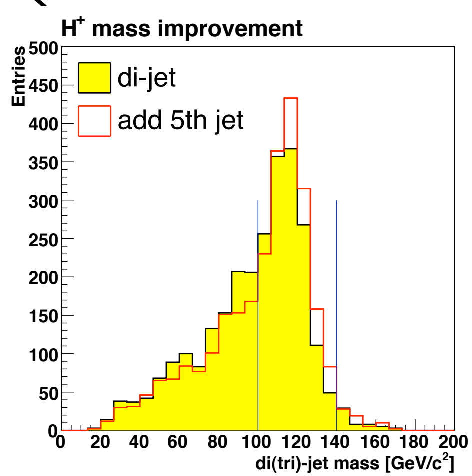
We extract a limit on the branching fraction $\mathcal{B}(t \to Zq)$ from a fit to the mass χ^2 distribution using templates constructed from the MC simulated mass χ^2 distributions of the FCNC signal and the SM backgrounds (Z+jets, SM $t\bar{t}$, and dibosons). The normalization of the dominant Z+jets background is the most difficult to estimate from data and MC simulations; therefore it is extracted from

http://www-cdf.fnal.gov/physics/new/top/2008/tprop/ChargedHiggs/chiggs_pub3.pdf http://www-cdf.fnal.gov/physics/new/top/2008/tprop/ChargedHiggs/chiggs_pub3.pdf

Charged Higgs







Use kine fitter

FIG. 5: Improved di-jet mass resolution adding a nearby extra jet to a closest leading jet.

Di-jet mass should be different

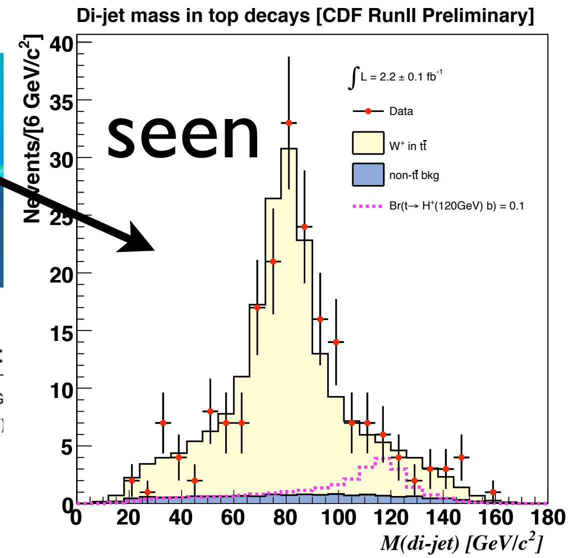
$$\chi^2 = \sum_{i=l,4jets} \frac{({p_T}^{i,fit} - {p_T}^{i,meas})^2}{{\sigma_i}^2} + \sum_{j=x,y} \frac{({p_j}^{UE,fit} - {p_j}^{UE,meas})^2}{{\sigma_{UE}}^2} + \frac{(M_{l\nu} - M_W)^2}{{\Gamma_W}^2} + \frac{(M_{jj} - {M_H}^{reco})^2}{{\Gamma_H}^2} + \frac{(M_{bl\nu} - M_t)^2}{{\Gamma_t}^2} + \frac{(M_{bjj} - M_t)^2}{{\Gamma_t}^2}.$$

Charged Higgs

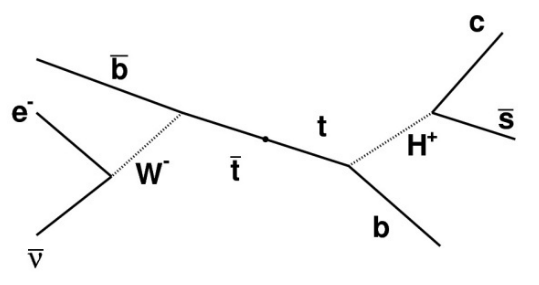
Searches for H±

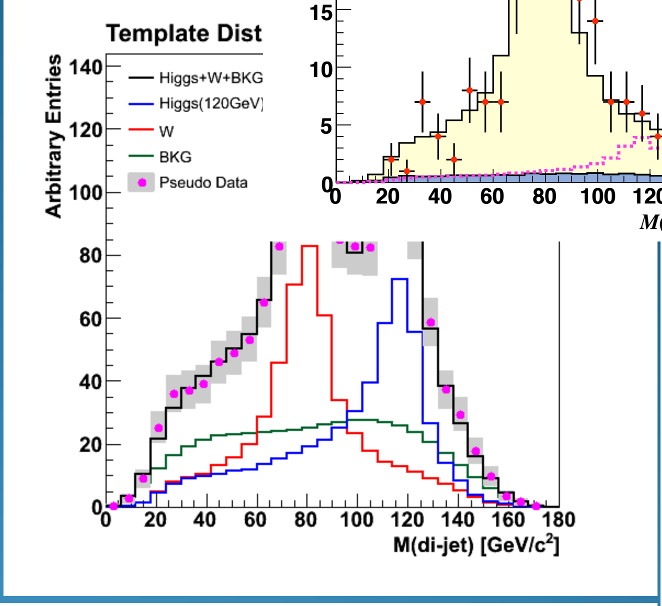
http://www-cdf.fnal.gov/physics/new/top/2008/tprop/ChargedHiggs/chiggs_pub3.pdf

L. Scodellaro Search for BSM Higgs at the Tevatron"



- Search for $t\bar{t} \to bH^+\bar{b}W^- \to bc\bar{s}\bar{b}l^-\bar{\nu}$
  - $W \to l\nu$ reconstructed
  - Two tagged jets





- Sensitive to MSSM production if $\tan\beta \leq 1$ and $M_{H\pm} \leq 130$ GeV/c²
- Dijet mass to separate $H^\pm \to cs$ from $W^\pm \to qq$ and backgrounds
- No excess, limits on BR($t \to H^\pm b$)
  - BR($H^\pm \to cs$) = 100% assumed

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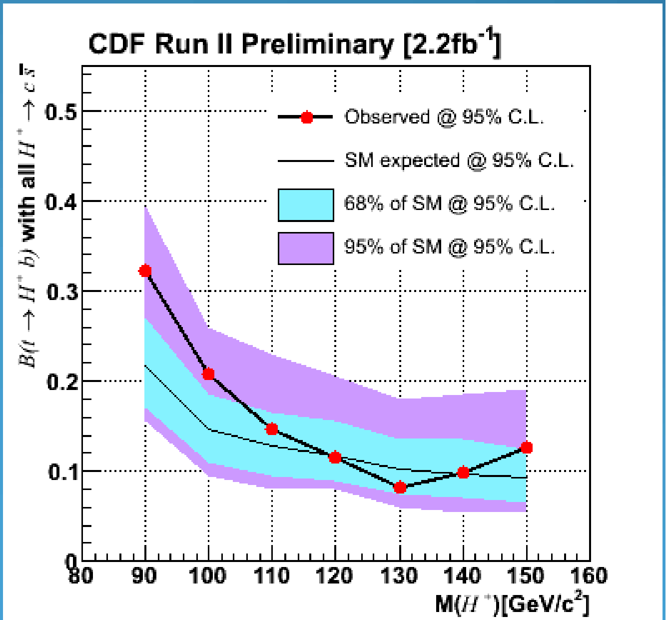
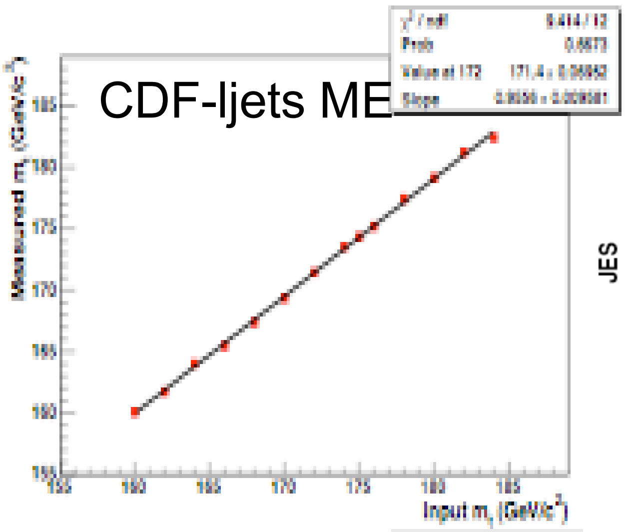
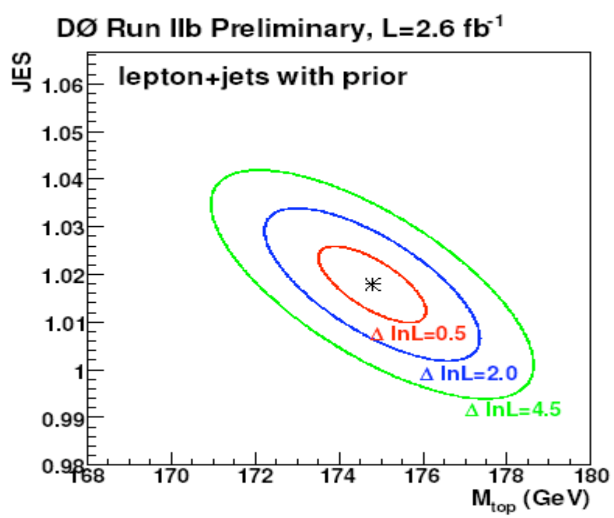


Methods of Mass Measurement

- Calibrate method w/pseudoexperiments
  - Fit mass estimators for ttbar and BG
  - calibrate fitted m_t vs. true m_t





- Jet calibration dominates m_t measurement
  - But, top offers W→jj resonance in all-jets and l+jets channels
  - Simultaneously fit m_t and jet energy scale (JES)

- World avg. now systematics dominated
  → common consensus on definitions and combinations

Systematic Category	Source (examples):
Physics modeling	FSR/ISR Hadronization/underlying events* Background model* Multiple interactions PDFs Color reconnection*
Detector modeling	Residual JES (6j, l+jets)* JES* b/light quark JES* B-tag efficiency Jet energy resolution
Method	MC calibration Template statistics (template)*

*currently >= 0.5 GeV

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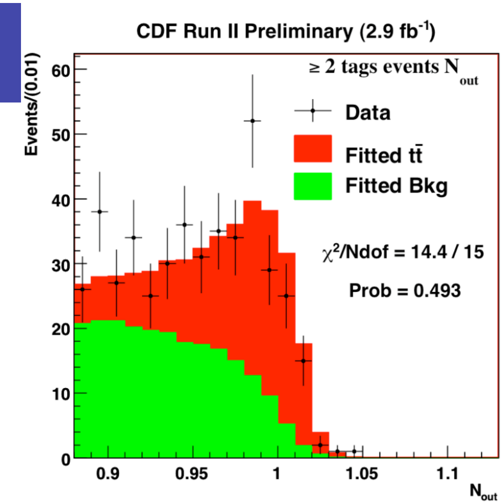
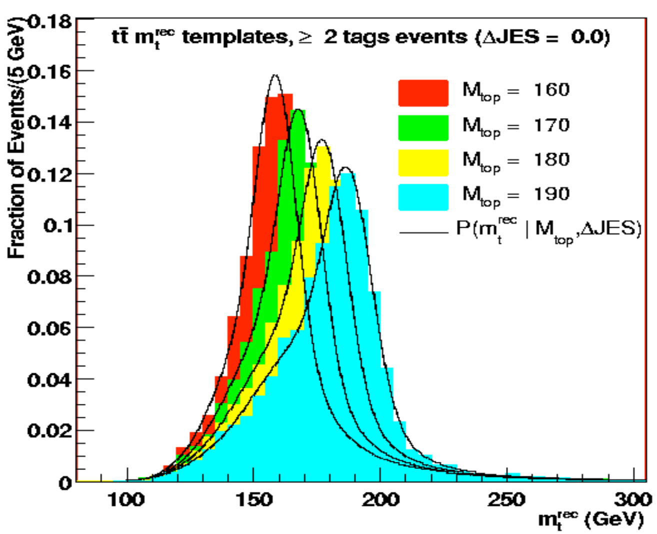
All-hadronic Channel

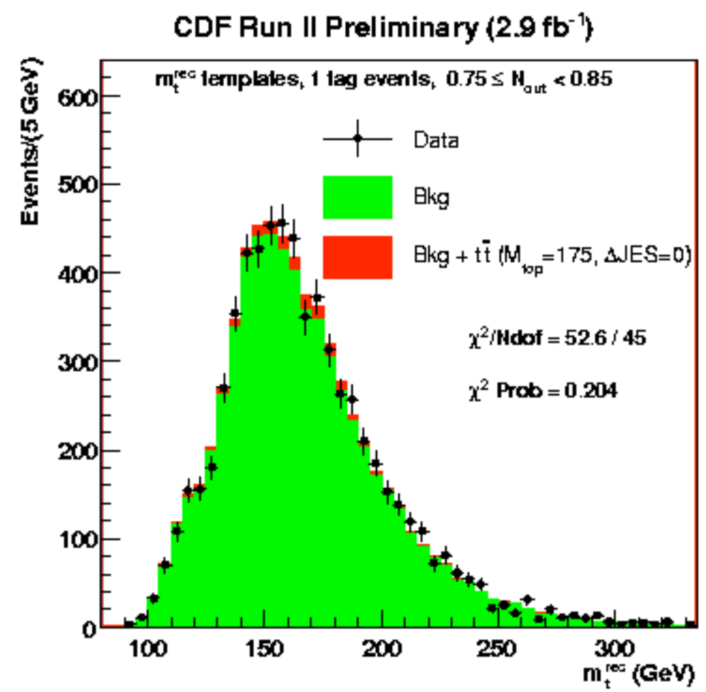
- Events selected, 2.9 fb^{-1}
  - Neural-network
  - Jet shapes discriminate quark and gluon jets: 25% improvement!
- Compare reconstructed W and top masses with MC expectation

$$\chi^2 = \frac{\left(m_{jj}^{(1)} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(m_{jj}^{(2)} - M_W\right)^2}{\Gamma_W^2} + \frac{\left(m_{jjb}^{(1)} - m_t^{rec}\right)^2}{\Gamma_t^2} + \frac{\left(m_{jjb}^{(2)} - m_t^{rec}\right)^2}{\Gamma_t^2} + \sum_{i=1}^{6} \frac{\left(p_{T,i}^{fit} - p_{T,i}^{meas}\right)^2}{\sigma_i^2}$$

  - Try different jet assignments
  - Use W→jj constraint to extract jet energy scale

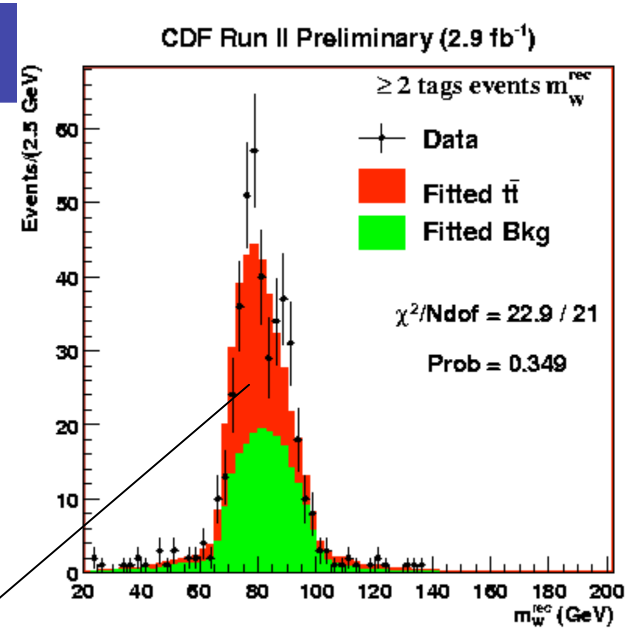


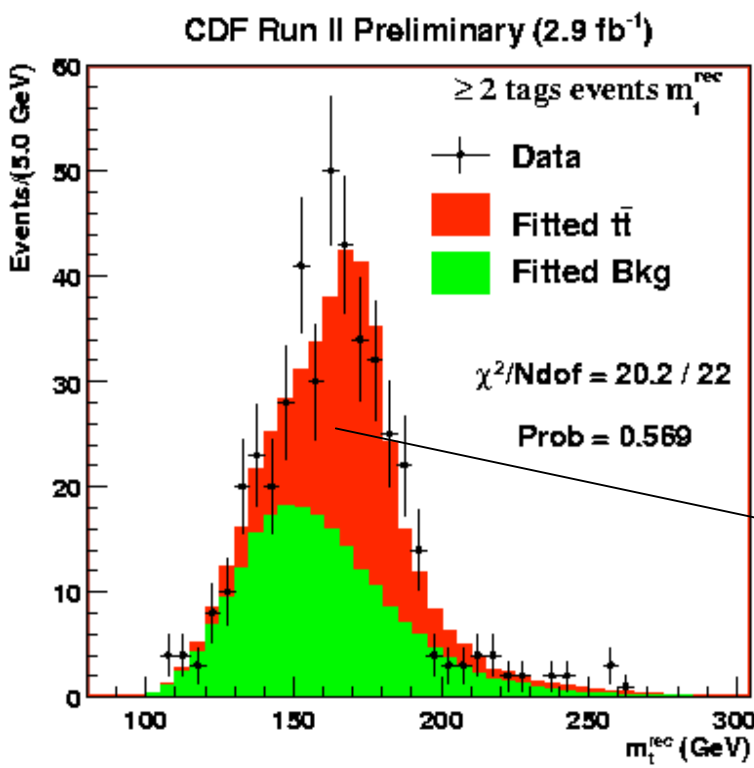


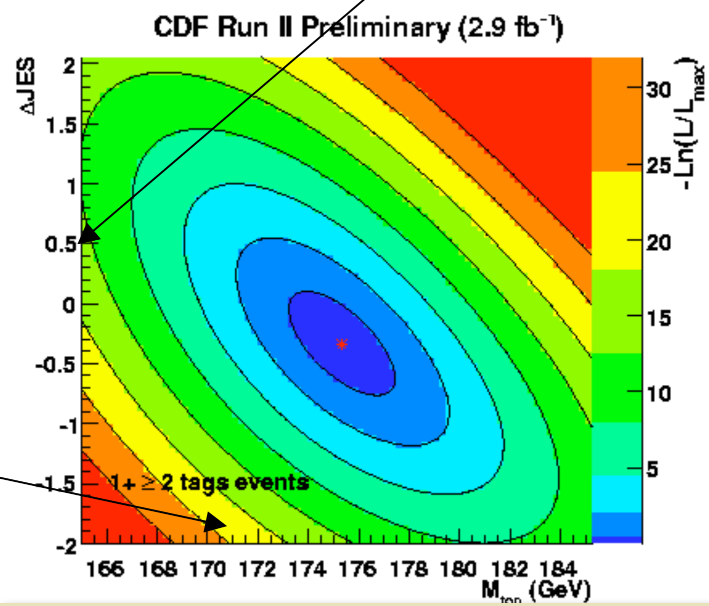


All-jets Mass

- Reconstructed W and top
  - Fit shapes from ttbar and BG
- Largest systematic uncertainties
  - Residual bias, residual JES, color reconnection







$$m_t = 174.8 \pm 2.4(\text{stat} + \text{JES})^{+1.2}_{-1.0}(\text{syst})\ \text{GeV}$$

$$\Delta\text{JES} = -0.30 \pm 0.47(\text{stat} + m_t)^{+0.34}_{-0.37}(\text{syst})$$